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A Review of Power Quality and Standards, Issues, Corresponding Mitigation Techniques in Microgrids

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Abstract:
The main components of Microgrids (MGs) consist of numerous Renewable Energy Sources (RESs) that utilize a variety of technologies built on power electronics. Nevertheless, it exhibits an erratic output, thereby resulting in various forms of power quality incidents. Consequently, there has been the establishment of standards and the implementation of mitigation strategies. Recent years have suggested several strategies and standards to address power quality difficulties caused by the integration of MG. expect the power quality to decline as the use of switching devices continues to increase. Additionally, these devices are particularly susceptible to damage. To experience a breakdown due to inadequate power quality, the globe is propelled by carbon emissions to substitute conventional electricity with as much renewable generation as is feasible. Researchers have been drawn to the aforementioned circumstances in order to find and propose mitigation approaches for power quality issues. The goal is to enhance the performance of MG that use renewable energy resources**.** This paper gives a review on power quality, standards and explains issue of power quality, harmonic mitigation techniques.

Index Terms: Power Quality, Power Quality Issues, Mitigation Technique, Harmonic Mitigation, Carbon Dioxide (CO_2) Emissions, Sustainability.

I. INTRODUCTION

The exponential increase in global energy consumption is the primary factor driving the extensive utilization of fossil fuels and the subsequent escalation of greenhouse gas emissions. The renewable power generation sector has been motivated by significant concerns to do thorough research on how to substitute existing fossil fuels and mitigate environmental issues. Because of this factor, the installation and incorporation of Renewable Energy Sources (RESs) into the existing power grid have experienced significant growth in recent years. Presently, more than 33 percent of the installed power-generating capacity worldwide comes from renewable sources. [1]. Nevertheless, because RESs rely regarding the climate, specific kinds the fuels, such as fuel cells, and only a limited amount of electricity, they are integrated with current Additionally, a lot of nations support the integration of Distribution Generators (DGs) powered by renewable energy sources into a distribution network called Distributed Energy Sources (DESs). DGs and Energy Storage Systems (ESSs). Thus, we create the notion of a Microgrids (MGs), a collection of DESs and interconnected loads that operate within well-defined electrical limits and function as a unified grid [2].

RESs, including as Photovoltaic (PV) and Wind Turbines (WT), as well as low-emission DGs, like micro turbines and fuel cells, are currently the focus of technological design for DG systems. Therefore, the widespread implementation of MG plays a significant role in decreasing Carbon Dioxide (CO_2) emissions and aiding in climate change mitigation. Nevertheless, power quality issues provide a significant technological barrier to the management and functioning of both independent and grid-connected systems. The structure, performance, and mode of operation (grid-connected or freestanding) of DESs in MG are major concerns. W[1]hen there are a lot of DGs, they can cause problems with power quality, such as voltage harmonics, current harmonics, voltage sag or swell, fluctuation, imbalance, malfunctioning safety devices, overloading, and failure of electrical equipment [3, 4].

The phrase "power quality" refers to describe the maintenance of a power distribution that closely resembles a sinusoidal waveform at the specified voltage magnitude and frequency. MGs connected into main grid must consider this crucial feature. Switching devices and sensitive, nonlinear loads can have an impact on quality of power of a MG while it is operating. Additionally, the intermittent nature of DGs, such as solar energy and wind power, can significantly affect the power quality of a MG. Hence, it is imperative to make a crucial decision to implement sophisticated control systems in order to mitigate the adverse impacts resulting from the connection of distributed generation to the grid. In a power quality-sensitive market, the pricing of on-grid electricity will be negatively affected by poor power quality [5, 6].

In order to guarantee the excellent quality of the power output, several standards and requirements have been established recently due to the growing number of MG installations [7], [8]. The guidelines address several aspects concerning the incorporation of technological challenges and power quality concerns, which have been thoroughly examined and evaluated in existing literature [9] and [10]. Verification of conformity with standard and Grid Code (GC) requirements must be carried out during the progress of

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integrating RES. Several studies have attempted to provide evidence of adherence and confirmation to the technical regulations outlined in contemporary GCs and other standards. An approach to addressing voltage sag in MGs is suggested in [11] based on IEEE standards and in [12] based on German GC. An assessment was conducted in [13] to determine if the MG connected to the main grid adhered to the frequency and voltage standards outlined in the German GC. In recent standards, the problems of swell, unbalance, fluctuation, and harmonics in MG systems are addressed by employing external devices like Static Synchronous Compensators (STATCOM) [14], [15], Dynamic Voltage Restorers (DVR) [16], Static VAR Compensators (SVC) [17], [18], and unified Power Quality Conditioners (UPQC) [19].

II. MG Power Quality and Standards Overview

The MG exhibits unique behavior and encounters distinct issues related to its operation and power quality that differ from those encountered by conventional systems. The challenges of MG power quality arise from its unique structure, operational mode (either connected to the grid or freestanding), type and configuration of MG distributed technologies [20]. The problems related to MG power quality can be broadly categorized into four main groups [21]. The first category concerns the operational conditions of the MG DESs, in particular, the variations in power production from renewable energy sources such as wind and photovoltaic. The power electronics components of the DESs generate harmonics in current and voltage, which constitute the second category. Additionally, the MG system can produce voltage and current harmonics of the third type due to the presence of nonlinear loads. The fourth category is MG voltage imbalance. The issue of unbalance typically arises from the presence of unbalanced three-phase loads and the inclusion of single-phase loads in the MG. In addition, with the significant increase in MG integration over the years, certain Grid Controllers (GCs) have begun implementing stringent criteria for power quality issues, including voltage sag and voltage swell, when integrating MGs into the primary power grid.

Power quality is a significant issue in small-scale island systems due to the existence of nonlinear and unbalanced loads, which make up a significant fraction of the overall load. This scenario gives rise to voltage issues such as distortion, fluctuation, and voltage sags and swelling in a system that is comparatively lacking in strength [22].

Because the load is not evenly spread out and the impedance is much higher in islanded mode than in grid-connected mode, disturbances like distortion and voltage unbalance are more likely to happen. The grid-connected mode commonly encounters disturbances like uneven utility voltages and voltage sag [23]. Sources like wind, solar, and fuel cells produce extremely inconsistent voltage, making direct connection to the power grid impractical. We analyze the power quality incident by examining the progress in establishing standards for quantifying power quality. The establishment of standards significantly influences the study of power quality. There are two worldwide standards in existence, specifically the IEC and IEEE. Countries with a high installation of renewable energy sources, like Germany and the US, have enhanced their grid codes using new standards [24], [25], and [26]. Many studies have used power quality standards, which define the acceptable limits for distortions and deviations in a variety of electrical parameters such as current, voltage, and power factor. Table I summarizes the standards used to define the power quality characteristics.

IEEE Standard 1159-2009, an updated version of IEEE Standard 1159-1995, outlines the power quality criteria and specifications for power systems. All terminologies and power quality indexes are well defined and stated. The standard incorporates specific restrictions and criteria for power quality, including voltage sag, voltage swell, and over-voltages [27].

TABLE I: A list of some PQ parameter standards.

IEEE stand. 519-92	Suggestions for the power system's harmonic requirements and specifications
IEEE stand. 1159-95	Recommended specifications and requirements for power quality in the power system
IEEE stand. 1100-99	Suggested specifications and requirement for grounding and powering sensitive electronic device
IEEE stand. 1366-2012	Electric power distribution reliability indices
IEC 61000-3-2	Harmonic current emission limits
IEC 61000-4-14	Flicker and fluctuation meter- functional requirement and configuration specification

III. MICROGRID POWER QUALITY ISSUES

The power quality of a system is determined by numerous international standards. IEC 61000 defines power quality as the assessment of an electrical system's characteristics at a particular point in time, using a set standard technological criteria [28].

In contrast in comparison to traditional power systems, the MG displays distinct behavior and encounters specific problems with power quality. Quality of power challenges of MGs can be broadly categorized into four main groups. The first category is the result of a specific cause.

Variations in output from solar power and wind energy in the MGs DGs impact the operational conditions. The second group includes the harmonics generated by Power electronics components and irregular loads in the DESs. The third type focuses on maintaining the MGs stability during and after a fault. The presence of single-phase and unbalanced three-phase loads leads to unbalanced phase voltages, which is the fourth category of power quality issues in MGs [28].

RES, such as solar, wind, and fuel cells, will provide actual power to the MGs instead of reactive power, which leads to voltage problems associated with reactive power. This connection between RES leads to further power quality issues. Power quality is a crucial concern due to the significant presence of nonlinear and unbalanced loads in small-scale island systems. These loads can cause voltage problems on a relatively weak grid, such as unbalance, harmonics, and sag/swell in voltage. The mathematical representation of the root mean square (RMS) value of voltage is provided by Eq. (1) as follows:

$$V_{ith}^{rms} = \sqrt{\frac{1}{M}\sum_{j=1}^{ith+M} V_j^2} \tag{1}$$

In grid-connected mode, the most common problems are voltage sag and imbalanced voltages. The sag, is typically caused by faults, is a significant power quality issue in MGs that frequently disrupts the operation of critical electronic equipment. Another significant power quality issue is swell, which exhibits contrasting behavior to sag [29].
Nonlinear loads, electronic inverters, computer drives, and variable-speed motors are examples of sources that can produce harmonics in MGs. At the moment, power electronic devices are crucial to distributed generation and RES grid integration.
Power electronic devices serve as an interface between the RES and the electrical grid. These devices introduce harmonics into the system, leading to voltage distortion, increased losses, and potential malfunctions in protection relays and other control units. To maintain the system's Total Harmonic Distortion (THD) below acceptable thresholds, it is necessary to decrease the THD. Harmonics can give rise to substantial problems in the MG is given by Eqs. (2, 3) as follows:

$$THD_v = \frac{\sqrt{\sum_{i=2}^{N} V_i}}{V_1} = \frac{\sqrt{V_{rms}^2 - V_1^2}}{V_1} \tag{2}$$

$$THD_I = \frac{\sqrt{I_{rms}^2 - I_1^2}}{I_1} \tag{3}$$

Unequal voltage distribution can cause harm to both power electronics and components within the MG power system [30]. Within in an environment that lacks balance, power systems will experience a greater loss of power and a decrease in stability [29]. Variations in solar radiation, wind speed, battery charge/discharge, and load frequently cause the voltage in an MG to fluctuate [30]. The number of devices using high-frequency technologies has increased, leading to an increase in high-frequency noise above 2 kHz. Concern is being raised by this noise, especially Supra-Harmonics (SH) between 2 and 150 kHz. Examples of this type of equipment include solar and wind energy converters, computer power supply, and chargers for electric vehicles [31].

IV. MICROGRID POWER QUALITY IMPROVEMENT

The growing use of renewable energy sources in the low-voltage grid has led to a notable increase in focus to the mitigation of power quality issues in MG in recent years. Employ a range of devices and control mechanisms is to mitigate the danger of power quality issues in the entire power system.
Various control mechanisms, optimizations approaches, among others, have been developed to enhance microgrid power quality.

A. Optimization Methodologies

The Seeker Optimization Algorithm (SOA), a heuristic optimization algorithm, is employed to improve the power quality of a diesel generator system [32]. By controlling the generator's excitation and input power, the power quality is improved. The input power Supervisor utilizes Proportional–Integral–Derivative (PID) controller. The Second-Order Algorithm (SOA) dynamically adjusts the gains of the PID controller, significantly enhancing the power quality of the diesel generator system.
By employing a Triple Action Controller (TAC), it is possible to achieve regulation of voltage and frequency, minimize voltage Total Harmonic Distortion (THD), and control the current flow between inverters that are parallel [33]. Implementing a TAC control approach with droop and secondary optimized parameters can effectively decrease the circulating current between the inverters and enhance power sharing .
The control mechanism enhanced the overall dependability and power consistency of the system. In order to mitigate the presence of harmonics on the Alternating Current (AC) side of a hybrid MGs, Utilized are Power Filtering Compensation (PFC) kit modules and active power filters [33].
Harmonics of voltage and current as well as controller error form the hierarchical structure of the objective function [34].
We employ an intelligent fuzzy controller [23] to mitigate voltage imbalance and tackle power quality issues in a hybrid AC-DC micro-grid. The restoration of system voltage and frequency is achieved through the utilization of artificial neural networks and hybrid differential evolution optimization [35].
In [36], a power quality control technique is proposed that revolves on a residual generator based on observers. This strategy aims to reduce the impact of voltage sag, swell, imbalance, and harmonics in AC MG. The energy management system tries to minimize the overall cost of the system by coordinating the operation schedules of the MGs distributed energy supplies and loads. Simultaneously, the power quality algorithm keeps an eye out for and logs any power quality problems that can arise while the system is operating [35].

B. Alternative techniques and Contingency Plans

Third-Order Fundamental Extractor (TOFE) control technique is applied to a three-phase solar PV system coupled to a weak grid in order to reduce the harmonics in the grid current [37]. The goal of TOFE is to obtain the primary voltage for the purpose of grid synchronization. We employ the feed forward component to improve the dynamic reactivity of the system. Because of its faster response time, TOFE achieves steady state more quickly and requires fewer calculations.

To improve power quality and enable efficient power flow control, a Centralized Microgrid Controller (CMC) is utilized. The main objectives of the CMC are to ensure dependable and top-notch power distribution to the load, optimize the use of RESs, and facilitate seamless power transmission between different operating conditions. This study focuses on the THD of the source current and the methods to reduce voltage sag and swell. The reference for this work is [38]. The development of a variable reactor utilizing magnetic flux management [39] to limit fault current, control bidirectional power flow, lessen harmonic penetration, and adjust for voltage fluctuation in MGs. In order to improve power quality, a UPQC has been developed by the application of the Current Source Converter (CSC) architecture [40]. To make sure that the voltage and current THD values are within the allowed bounds, harmonic mitigation is used. In [41], Consensus control algorithms have been suggested as an adaptive method for redesigning harmonic impedance. Ref. [42] discusses the enhancement of power quality in Multi-Area MGs (MAMGs). Using DGs in conjunction Using active power filters is a workable way to reduce voltage imbalances and harmonics. A control approach is developed in [43] to improve quality in a hybrid MGs with multiple buses. The control approach of a multi-bus MGs incorporates the management of unbalanced and nonlinear loads. The techniques that tackle the problem of voltage unbalancing in MG are discussed in reference [44]. Ref. [45] demonstrates a hybrid AC/DC MG that adjusts voltage imbalance and harmonics using interactive power converters. Power electronic interfacing converters are used by the hybrid MGs to improve the effectiveness and affordability of providing unbalanced and harmonic management. The paper introduces a Fuzzy Hysteresis Current Controller (FHCC)-based inverter in order to improve power quality in MGs that have integrated renewable energy clusters and can operate in either grid-connected or autonomous mode. A fuzzy logic-based hysteresis current control loop is implemented to minimize power quality indices, including voltage characteristics (swell, sag, and imbalance), frequency characteristics (deviations), and total harmonic distortion. Table II presents a comparison of several control approaches for improving power quality.

TABLE II: A Comparison of different control methods in Microgrid for improving power quality

Issues	Methods	Outcomes	Remarks
Voltage sag/swell	DVR Improved Dynamic Voltage Restorer (DVR) compensation approach has been designed	Mitigation of voltage sag and Swell To eliminate balanced voltage sag with phase jump	Battery management system is needed to effectively deliver constant voltage during the charging or discharging battery mode
Voltage Unbalance	Interfacing inverter control Negative-sequence compensation based three-phase voltage correction strategy	Balanced phase voltages at the bus which the inverter is connected Reduced negative sequence currents and improved voltage profile	Unable to balance the phase voltages at other MG buses. Limited to MG with PV and BESS
Harmonics	Active power filters and power filter compensator(PFC) kit A third order fundamental extractor based control technique (TOFE) A magnetic flux control-based variable reactor	- Reduces harmonics in AC side of hybrid MGs To reduce the grid current harmonics in a three phase grid connected solar PV system operating in weak grid conditions For reducing harmonic penetration, regulating bidirectional power flow, limiting fault current and compensating voltage fluctuation in MGs	Complex computation Takes less time to reach steady state and requires fewer calculations Cost effective

V. HARMONIC MITIGATION TECHNIQUES

It is crucial to improve the effectiveness and quality of grid harmonic mitigation strategies. The methods for mitigating harmonics are generally categorized as

i) Passive techniques.
ii) Multi-pulse rectifier techniques.
iii) Active harmonic cancellation techniques.

Traditional harmonic mitigation devices, including AC and DC chokes, are commonly employed in low-power industrial applications due to their low cost, dependability, and simplicity [46]. The number 19 is enclosed in square brackets. The primary focus of the study was on utilizing passive harmonic techniques to analysis a low-distribution network that is connected to a grid and includes both single and multi-unit converters. The study demonstrates that the reduction of harmonics is influenced by the arrangement of the power grid. Furthermore, it reveals that the mitigation of current harmonics can be achieved at the system level by connecting a greater number of converters to the grid. In their work, the author introduced a modified three-phase power converter known as the 'Slim Direct Current (DC) Link Converter', which incorporates a smaller DC link capacitor. In these drives, the electrolyte capacitor is substituted by a smaller film capacitor [47].

MGs employ filters to mitigate THD. The utilizations of a shunt active power filter in a MGs system at the distribution level is employed to improve the power quality. The neural learning algorithm technique is employed to optimize the performance of the shunt active filter. We validate the effectiveness of the suggested technique and compare several pulse generation schemes using the Matlab/Simulink platform. A control approach utilizing an active power filter is presented to address the power quality issue caused by the integration of renewable sources, as discussed in [48]. In this study, the inverter transfers the electricity from the renewable energy source to the electrical grid. The inverter functions similarly to a shunt active power filter, injecting power into the grid. The inverter functions properly.

In two operational modes, mode I involves the injection of electricity from a renewable source to enhance power quality, while mode II functions as a shunt active power filter without power generation. A method is presented in [49] to decrease harmonic current utilizing Empirical Mode Decomposition (EMD) and intrinsic mode regression Support Vector Regression (SVR) theory. This method has been successfully applied to a MGs hybrid active power filter. EMD initially divides the harmonic current, and the SVR module then computes the expected values of each weighted harmonic [50].

VI. CONCLUSION

An MG network is a cutting-edge power network that has the ability to fulfill future energy needs, particularly in relation to smart grid technology and renewable electricity. Multiple electrical sources. The primary source of reliance in the MG network is RESs. Nevertheless, the output of RES (renewable energy sources) is unpredictable and relies on weather conditions, necessitating the need for numerous power electronics equipment. Therefore, the presence of power quality standards, measurement techniques, and methods for mitigating power quality issues are crucial elements for the development and expansion of MGs. This paper aims to explore several power quality mitigation approaches to improve the quality of power in a MGs, both when connected to the grid and when operating independently. Operational modes include both connected and islanded modes. This paper discusses strategies for improving power quality in a MGs, including harmonic abatement techniques, filters, and optimization techniques.

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